United States Patent Application for

FLOWER-SHAPED VERTICAL ALIGNMENT LIQUID CRYSTAL DISPLAYS WITH WIDE VIEW ANGLE AND FAST RESPONSE TIME

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FLOWER-SHAPED VERTICAL ALIGNMENT LIQUID CRYSTAL DISPLAYS WITH WIDE VIEW ANGLE AND FAST RESPONSE TIME

This invention claims the benefit of priority based on U. S. Provisional patent application 60/459,451 filed April 01, 2003.

FIELD OF THE INVENTION

This invention relates to a novel structure of vertical alignment (VA) liquid crystal displays (LCD), and more specifically, to a structure of a liquid crystal display (LCD) with flower-shaped vertical alignment (FVA) with fast response, high contrast ratio, wide view angle and method for making the FVA device.

BACKGROUND AND PRIOR ART

With the quick development and expansion of the liquid crystal display market, fast response, high contrast ratio and wide view angle are the main issues to improve the display quality. Fast response, high contrast ratio and wide view angle are critically required in large size monitors and television (TV) applications. At present, in-plane switching (IPS), multi-domain vertical alignment (MVA) and axially symmetric-aligned microcell (ASM) are the typical candidates for obtaining the high display quality in these areas.

The IPS concept was first published by R. A. Soref in Applied Physics Letters, vol. 22, p.165 (1973) and Journal of Applied Physics vol. 45, p. 5466 (1974). In 1992, Kiefer et al in Japan Display '92 p. 547, extended the IPS operating principle to display devices. The IPS liquid crystal display (LCD) works as the electric field is applied in the transversal direction and the liquid crystal (LC) molecules are rotated in the same plane as shown in Fig. 1 of this application. The IPS structure in Fig. 1 comprises an analyzer layer **10**, a liquid crystal layer **11** sandwiched between a top substrate **12** and a bottom

substrate **13** positioned above a polarizer **14** through which a backlight **15** is directed. The rubbing direction is indicated by arrows **16** and **17**. As a result, the IPS mode exhibits a wide viewing angle and high contrast ratio, while the response time is relatively slow at approximately 50 milliseconds (ms).

As shown in Fig. 2, Fujitsu Ltd. invented a super high quality MVA LCD published in SID Technical Digest, vol.29, p.1077 (1998), Fujitsu Science Technical Journal, vol. 35, p.221 (1999), and typically as disclosed in US patent 6,424,398 B1 in 2002. In Fig. 2, The chevron-patterned protrusions **21** and **22** are created on the upper and lower substrates to form multi-domain LCD cells in multiple independent directions. The devices provide a high contrast ratio higher than 300:1, view angle wider than 160 degrees, and a fast response of 25 ms. Since the horizontal gap between the upper and the lower protrusions must be less than 30 micrometers (μm) in order to obtain fast response time, the pixel alignment needs high precision. Thus, the design specification and preparation process are not easy and the aperture ratio is limited. In addition, the adopted LC materials are constrained to negative dielectric ones in order to realize the deformed homeotropic alignment effect in the voltage-on state.

The axially symmetric-aligned microcell (ASM) was developed by Sharp Corp. as disclosed in US Patent 6,014,188 in 2000 and published in the SID Technical Digest, vol. 26, p.575 (1995), and SID Technical Digest, vol. 29, p.1089 (1998) respectively. In the ASM mode, the liquid crystal alignment **30** shows spiral distribution and the polymer walls **31** are formed by ultra-violet (UV) exposure to construct microcell pixels **32** as shown in Fig. 3 of this application. The view angle of more than 120 degrees, high contrast ratio of 300:1 and a medium response time of 30 ms can be obtained in the ASM mode. Since the polymer network stabilizes the LC alignment in the microcells, the large-scaled precise control of the microcells and the long-term stability of them are the questionable problems for this mode.

In the above-mentioned modes, two linear polarizers are usually used. Recently, Iwamoto et al reported a MVA mode using circular polarizers in the 9th International Display Workshops, p. 85 (Hiroshima, Japan, Dec. 4-6, 2002). The light efficiency is improved. In the IPS mode, a rubbing process is necessary in order to achieve uniform LC alignment. The problems associated with the rubbing process are thin film transistor (TFT) damages, dust particle contamination, and static charges.

There is still a need to overcome problems with existing technology to obtain high quality displays for large monitors. As discussed above, IPS has a relatively slow response time and requires a rubbing process. MVA LCD has difficult design specifications, which results in a tedious preparation process. ASM requires precise control of the microcells and has problems with long-term stability. The present invention resolves many problems with current technology while providing a reliable, simple structure suitable for high yield mass production.

SUMMARY OF THE INVENTION

A primary objective of the invention is to provide a flower-shaped vertical alignment (FVA) mode liquid crystal display (LCD) with a protrusion structure using the circularly polarized light.

A secondary objective of the invention is to provide a FVA structure showing fast response time.

A third objective of the invention is to provide a FVA structure showing high contrast ratio.

A fourth objective of the invention is to provide a FVA structure showing wide view angle.

A fifth objective of the invention is to provide a LCD with simple structure and rubbing-free technique for high yield mass production.

A sixth objective of the invention is to provide a method for making a wide view angle, fast response, high contrast ratio liquid crystal display (LCD) with a flower-shaped vertical alignment (FVA).

According to the invention, there is provided a flower-shaped vertical alignment (FVA) structure liquid crystal display (LCD) with fast response, high contrast ratio and wide view angle comprising: a first substrate with a protrusion shaped electrode as the pixel electrode; a second substrate as the common electrode; aligning layers formed on said first and second substrates providing liquid crystal vertical alignment; liquid crystal materials filling a space between said first and second substrates as a liquid crystal cell; a linear polarizer and wide band quarter-wave film forming a circular polarizer; and, said circular polarizer disposed on exterior surfaces of said liquid crystal cell.

Further objects and advantages of this invention will be apparent from the following detailed descriptions of the presently preferred embodiments, which are illustrated schematically in the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 shows a general structure of in plane switching (prior art).

Fig. 2 shows a general structure of MVA developed by Fujitsu Ltd (prior art).

Fig. 3 shows a general structure of ASM developed by Sharp Corp (prior art).

Fig. 4 shows a general device configuration of the novel FVA mode of this invention.

Fig. 5 shows a typical pixel configuration of the novel FVA mode of this invention.

Fig. 6 shows the operation mechanisms of the novel FVA mode using positive and negative liquid crystal materials.

Fig. 7 shows the simulated LC director distribution of the FVA cell using a positive Merck E7 LC material as an example. The applied voltage is $V=6.5\ V_{rms}$.

Fig. 8 shows the voltage-dependent transmittance of FVA cell using a positive Merck E7 LC material at wavelengths λ=450nm, 550nm and 650nm, respectively.

Fig. 9 shows the response time of FVA cell using a positive Merck E7 LC material at $V=6.5\ V_{rms}$.

Fig. 10 shows the contrast ratio of FVA cell with Merck E7 LC material at $V=6.5\ V_{rms}$. The contrast ratio is calculated along the device's normal direction without the compensation films at wavelength λ=550 nm.

Fig. 11 shows the simulated time-dependent transmittance of Fujitsu's MVA cell using a negative Merck MLC-6609 LC mixture.

Fig. 12 shows the simulated LC director distribution of FVA cell with a negative LC mixture (Merck MLC-6609) at $V=9\ V_{rms}$.

Fig. 13 shows the time-dependent transmittance of FVA cell with a negative LC mixture (Merck MLC-6609) at different Δn values. Cell gap d=4 μm, $V=9\ V_{rms}$ and λ=550 nm.

Fig. 14 shows the response time of the FVA cell with MLC-6609 LC mixture at $V=9\ V_{rms}$ and $\Delta n=0.15$.

Fig. 15 shows the contrast ratio of FVA cell using a negative $\Delta\varepsilon$ Merck MLC-6609 LC mixture at $V=9\ V_{rms}$. The contrast ratio is calculated at normal incidence and λ=550nm. No compensation film is used for this simulation.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Before explaining the disclosed embodiments of the present invention in detail it is to be understood that the invention is not limited in its application to the details of the particular arrangements shown since the invention is capable of other embodiments. Also, the terminology used herein is for the purpose of description and not of limitation.

The invention provides a new device structure for achieving fast response time, high contrast ratio and wide view angle using the circular polarizers. It is rubbing-free and with a simple preparation process, where both positive ($\Delta\varepsilon>0$) and negative ($\Delta\varepsilon<0$) dielectric LC materials can be used. Fig. 4 shows a typical proposed device configuration comprising, a first polarizer layer **40** at approximately 90°, a vertically aligned liquid crystal **41,** sandwiched between a wide-band quarter-wave film **42** at approximately 45° and a wide-band quarter-wave film **43** at approximately 135°, and a second polarizer layer **44** at approximately 0°. Two broadband quarter-wave films are placed before and after the crossed linear polarizers. The principal axis of the first linear polarizer and the first broadband quarter-wave film is arranged at approximately 45 ° to form the front circular polarizer. It has a left-hand circularity. Similarly, the principal axis of second linear polarizer and the second broadband quarter-wave film is arranged at approximately 45 ° to form the rear circular polarizer with the right-hand circularity. The LC molecules are homeotropically aligned without a rubbing process and the cell is in the vertical alignment (VA) mode at null voltage state.

The typical pixel configuration is indicated in Fig. 5 wherein, the top indium tin oxide (ITO) substrate **50** has an empty hole **51** and the bottom ITO substrate **52** has protrusions **53** in the form of wall-bumps. The empty hole **51** in the ITO layer can have

various shapes, such as circular, elliptical, ring-shaped, square, rectangular and hexagonal. To improve the filling factor, the ring-shaped ITO can be changed to a hexagon. The ring-shaped ITO is used as an example for calculations. When there is no voltage applied, the incident light is completely blocked by the crossed circular polarizers and an excellent dark state is obtained. When the voltage is applied, the fringing electric fields surrounding the top ring ITO and bottom protrusion are created. The bottom protrusion electrode may have a variety of shapes including, but not limited to, conical, spherical, semi-spherical tower, pyramid and column-like structures.

Referring now to Fig. 6, the LC directors **60** and **61** are between a top substrate, as identified in Fig. 5 as **50** and a bottom substrate **53**, with $\Delta\varepsilon>0$ reoriented along the electric field direction, and the LC directors **62** and **63** are between the same top and bottom substrate, as described in Fig. 5, with $\Delta\varepsilon<0$ reoriented perpendicular to the electric field direction. Therefore, light transmits the crossed circular polarizers. A contrast ratio >500:1 can be achieved relatively easily. The LC director distribution looks like a flower blossom **64** and **65** in this electric field ON state when observed in the cell normal direction. This is why this operation mode is named as the flower vertical alignment (FVA) mode.

For explanation and comparison purposes, the following two embodiments using $\Delta\varepsilon>0$ and $\Delta\varepsilon<0$ LC materials, respectively, are described.

Embodiment 1: Positive ($\Delta\varepsilon>0$) dielectric anisotropy

The LC device structures of the present invention are shown in Figs. 4, 5 and 6. In Fig. 5, the diameter of the ring-shaped hole **51** on the top substrate **50** is approximately 8 micrometers (μm). A conic ITO protrusion **53** on the bottom substrate is approximately

1.5 μm in height. The cell gap between the top and bottom substrates is approximately 4 μm. A positive Δε LC material, E7 from Merck Company has the properties: birefringence Δn=0.215, dielectric anisotropy Δε=14.3 and rotational viscosity γ_1=0.19Pas) is aligned vertical to the substrates in the initial state. Its azimuthal angle is approximately 0.5°, and the pretilt angle is approximately 89.5°.

Fig. 7 is the simulated LC director distribution of this embodiment when the applied voltage is 6.5 V_{rms}. The LC directors are reoriented along the electric field direction due to the fringing field effect. From the plan view, the LC directors look like a flower blossom, forming generally expanding concentric patterns.

Fig. 8 shows the voltage-dependent transmittance of the device at three primary wavelengths λ=450 nm, 550 nm and 650 nm, respectively. After taking into account the optical losses of circular polarizers, the transmission is 19% at 6.5 V_{rms} for the wavelength λ=550 nm. The device has a fast response time of 12 ms (rise + decay) when a 6.5 V_{rms} voltage is applied to the cell. Results are shown in Fig. 9. The FVA mode also exhibits a high contrast ratio, defined as T_{on}/T_{off}. From Fig. 10, the contrast ratio exceeds 500:1 at the device's normal direction. In this calculation, no compensation film is used. It is known that a uniaxial film and a negative birefringence film are needed for a VA mode to exhibit a wide viewing angle. [S. T. Wu and D. K. Yang, *Reflective Liquid Crystal Displays* (Wiley, Chichester, 2001); Chap. 12].

For the comparison purpose, the Fujitsu's MVA mode was chosen as the benchmark. Fig. 11 shows the transmittance of Fujitsu's MVA mode using negative LC mixture MLC-6609 (Merck Company: birefringence Δn=0.0777, dielectric anisotropy Δε= -3.7 and rotational viscosity γ_1=0.16Pas) under the same cell conditions. The

maximum transmittance of the MVA cell is 22%. Thus, our FVA mode has compatible transmission efficiency to that of Fujitsu's MVA mode. The major advantage of the novel FVA mode is in the faster response time.

The decay time of a LC cell is proportional to $\gamma_1 d^2/K\pi^2$; where d is the cell gap, γ_1 is the rotational viscosity and K is the corresponding elastic constant. For a LC, the following relationship holds: $K_{33}>K_{11}>K_{22}$. Owing to the molecular structure and shape differences, a positive $\Delta\varepsilon$ liquid crystal possesses a lower rotational viscosity (γ_1) and larger bend elastic constant (K_{33}) than its negative $\Delta\varepsilon$ counterpart. As a result, the VA using positive $\Delta\varepsilon$ LC exhibits a faster response time than that of a negative $\Delta\varepsilon$ LC. This explains why the novel FVA mode disclosed herein has faster response time than that of the MVA mode.

Embodiment 2: Negative ($\Delta\varepsilon<0$) dielectric anisotropy

The LC device structures, as earlier noted, are shown in Figs. 4, 5 and 6. The diameter of the ring-shaped hole on the top substrate is approximately 9 μm. A conic ITO protrusion is on the bottom substrate with the height of approximately 2 μm. The cell gap between the top and bottom substrates is approximately 4 μm. A negative $\Delta\varepsilon$ LC mixture (MLC-6609 from Merck) is aligned vertically in the cell in the initial state. Its azimuthal angle is approximately 0.5° and the pretilt angle is approximately 89.5°.

Fig. 12 shows the LC director distribution of this embodiment when the applied voltage is 9 V_{rms}. The LC directors are reoriented perpendicular to the electric field direction due to the fringe field effect. As in Fig. 7, the LC directors have the appearance of a flower blossom in the plan view. The flower blossom appears as generally expanding concentric patterns.

Fig. 13 is the time-dependent transmittance of the device at different Δn in the rise period at λ=550 nm. The maximum transmittance reaches 21% at Δn=0.15, which is comparable to that of Fujitsu's MVA mode. As shown in Fig. 14, the device response time (rise + decay) is as short as 10 milliseconds (ms) when 9 V_{rms} is applied to the cell. Fig. 15 plots the voltage-dependent transmittance of such embodiment. A contrast ratio higher than 500:1 is obtained. Therefore, the novel FVA mode of the invention is particularly suitable for liquid crystal television (LC TV) and monitor applications.

While the invention has been described, disclosed, illustrated and shown in various terms of certain embodiments or modifications which it has presumed in practice, the scope of the invention is not intended to be, nor should it be deemed to be, limited thereby and such other modifications or embodiments as may be suggested by the teachings herein are particularly reserved especially as they fall within the breadth and scope of the claims here appended.